NGSS Compliance:
3-5-ETS1-(1-3); 3-PS2-1; 5-PS2-1

Water Rocket Science

Introduction

A water rocket is basically an upside-down soda bottle that has fins and a nose cone attached to it. The rocket may also have a “recovery system” attached to it for safe landing (like a parachute or streamers). The rocket works by putting some water into the bottle, attaching the rocket to a “launch device” that includes a rocket release latch mechanism, pressurizing the bottle with compressed air, and then releasing the latch mechanism to launch the water rocket. The air pressure inside the bottle forces the water downward through the bottle nozzle, and the reaction force (Newton’s third law of motion) accelerates the rocket upward into the air. When the rocket reaches its peak altitude, the recovery system is engaged, and the rocket floats safely back down to the ground.

Figure 1. Water rocket made from a 2L bottle and specialized fins, photographed at liftoff.

Objective

In this exercise, you will learn to build your own water rockets and we will launch them in your school play area. All students will use a single two-liter bottle as the base.

You will build your water rocket as part of a team. Your team’s design will have the following constraints:

- Teams may only use 2L bottles for the pressurized water unit.
- Teams may only use the materials provided in the class to build the rocket and recovery system.
- Teams are limited to a total assembly time of two hours (time not spent in the classroom may be spent at recess or after school).

There are three main objectives to building and launching your water rocket:

- Teams shall design their rocket to be stable during flight, and test their rockets for stability ahead of the rocket’s actual flight.
- Teams shall design their recovery system so that the rocket falls slowly to the ground so that the risk of damage or injury due to the falling rocket is kept to a minimum.
- Teams should determine, through Internet research and testing, which combination of fins, nose cone and quantity of water will enable their rocket to travel as high as possible (all rockets will be pressurized to the same 100PSI).

A prize will be awarded to the team whose rocket travels the highest while maintaining the requirements of stability and safe recovery. We will record both the apogee and the fall time of each rocket, and we will record the data in a table. We will graph the data to determine which rocket designs resulted in the highest altitude, and we will learn what features of the recovery system increase or decrease fall time. Rockets that do not travel stably upward or those that fall to the ground too hard will not be eligible for the prize, regardless of how high the rocket travels.

Several templates for fins and nose cones will be provided to the class. *Not all fins and nose cones are equal. Some will give better performance than others.* If you do a good job of Internet research and plan your rocket construction ahead of time, you will have a better chance of knowing which combination of fins, nose cone and amount of water will help your rocket travel the highest.

Principle of Operation

The rocket is constructed by building a nose cone, fins, and parachute around an empty 2L bottle, as shown in Figure 2. The rocket makes use of a combination of pressurized air and water as the propellant. Water is placed in the bottle, the bottle is sealed at the bottom with a special mechanism (described later), and air is forced into the bottle using some form of air compressor. The pressurized air in the bottle pushes against the interior walls of the bottle and the top of the water basin. When the latch mechanism at the bottom of the bottle is released, the water is expelled through the nozzle due to the pressurized air in the bottle. This expulsion provides the thrust needed to accelerate the rocket upward.

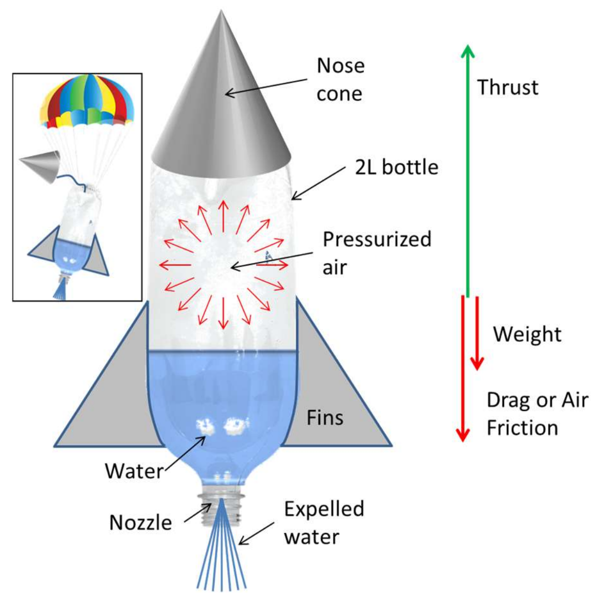


Figure 2. Illustration of a water rocket and the forces acting on it. Inset drawing shows rocket with parachute recovery.

There are three forces acting on a rocket in air:

- Thrust, the force acting on a rocket to push it upward;
- Weight, the force acting on a mass due to earth's gravity causing it to fall or slow down;
- Drag or Air Friction, the force due to the interaction between the rocket's surfaces and air molecules to slow the rocket down during flight.

Thrust tends to push the rocket upwards, while the combination of weight and air drag cause the rocket to slow down, and eventually to fall. The direction of each force is indicated by the green and red arrows to the right of Figure 2.

Finding ways to improve thrust, and to reduce weight and drag, will allow your rocket to travel to higher altitudes. Thrust can be improved by choosing the right water proportions, and increasing the air pressure inside the 2L bottle. Weight can be minimized by choosing lightweight materials. Drag can be minimized by keeping all of the rocket's surfaces smooth, eliminating sharp surfaces, and choosing fin and nose-cone types that keep air drag as low as possible. Exploring all of these possibilities, and making the most of them, will allow your team to engineer the water rocket that will travel highest.

Internet Research (homework before the lab)

Being able to answer the questions below will help you be a better rocketeer. The easiest way to gather information to engineer your rocket is to use an on-line search engine (such as Google) and simply ask it a question to which you want to know the answer. For example, when we talk about making the best fin type, you can ask Google, "What is the best fin shape?" Google will present several links that are the best matches to your question. Click on some of those links and try to find a good answer.

Record each question in your lab book, Google it, and research the answer. When you think you have a good answer, write it down in your notebook. It is also important to record the *source* of your information. The source is the location (a web site/address, book, magazine or the name of an expert in the field) that provided you the answer (hint: you didn't get your answer from Google, but usually from the web page to which Google directed you).

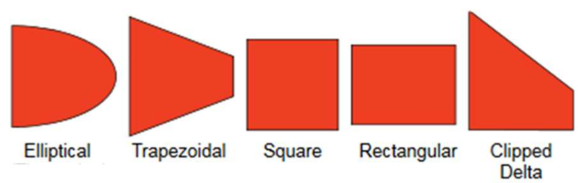


Figure 3. Possible fin types that you can use for building your water rocket.

Engineering research is *collaborative*. That means you can work with your teammates and even other classmates to get to the best answer quickly. When you do this homework assignment, you do not have to work alone. E-mail, call, text or FaceTime teammates and classmates, and work through the answers together. More minds working to solve a problem together are better than single minds working separately.

So with that preliminary stuff out of the way, here are the research questions and instructions:

1. What does it mean for a rocket to be stable during flight? Name at least two things can you do to improve your rocket stability.
2. You are presented with several choices of rocket fin in Figure 3. Which one is likely to give the least drag, and therefore make your rocket fly highest?
3. You are presented with several choices of rocket nose cone in Figure 4. Which one is likely to give the least drag, and therefore make your rocket fly highest? Which nose cone is really bad for drag?
4. How much water should we put in the rocket? (Optional) Why would the rocket fly not as high if we put in too much water? Why would it fly not as high if we put in too little?
5. Research parachute recovery systems on-line to learn simple ways of how to build one into

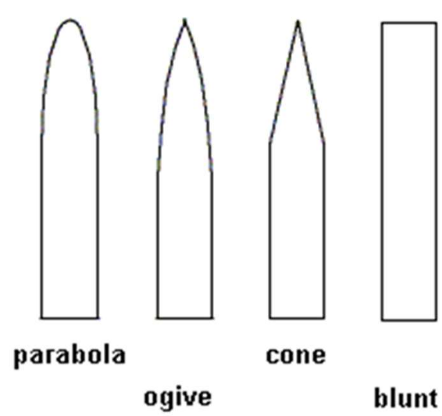


Figure 4. Possible nose cone types that you can use for building your water rocket.

your own water-rocket design. Within your notebook, propose and sketch out a recovery design. To help you get started, here are some web sites that show examples:

   a. http://www.orgsites.com/va/bristolwaterrockets/_pgg5.php3
   b. http://txsnapper.eezway.org/waterrocketguy/ezd.html
   c. http://www.rocklin.k12.ca.us/staff/pmorrison/ConPhys/Rockets/DrawYourRocketDiagram.htm

6. Go here: http://ez-launch.com/getting-started/, and learn a little bit about the launcher we plan to use. There is no need to write down anything in your notebook for this task.
7. (Optional) How might you shape the fin edges to reduce the drag even more?
8. (Optional) Learn about ways to test your rocket for stability on the ground, so you can be sure that the rocket is stable during flight. This stuff is a *really* advanced read, so don't worry about it if your eyes gloss over. We'll go over stability testing in class. In the meantime, here are a couple of sites to check out:
   a. http://www.rockets4schools.org/images/Basic.Rocket.Stability.pdf
   b. www.rocketryforum.com/attachment.php?attachmentid=1883&d=1234361832

Classroom Exercise: Rocket Build

Work in groups of two to four. Each table will need the following supplies:

- 1 or 2 empty 2L bottles (save the caps)
- 1 16x20" Elmer's posterboard
- 1 roll transparent packing tape
- Assorted Styrofoam balls
- 1 sheet per rocket of Cardstock, 65# weight
- 1 spool thread
- 1 trash bag, Glad 4gal
- Scissors
- Rubber bands
- Fine-point marker
- Sandpaper
- (optional) Five-minute epoxy

Construct the following pieces for your rocket:

- Nose cone. Choose one of the options below.
  - *Pointy*: Roll the cardstock into the shape of a cone. Be sure the base is wide enough to fit entirely over the top of the bottle. Secure the side of the cone with a small strip of packing tape. Trim the base of the cone until it is flat and fits comfortably over the top of the bottle. Do not attach the cone to the bottle yet.
  - *Parabolic*: Center a Styrofoam ball on top of the bottle. Carefully apply tape around the ball from all sides. Shape the tape into a smooth contour all around. Alternatively, you can use sandpaper (outside of class) to sand down the Styrofoam to the shape of a parabola, and tape the shaped cone directly to the top of the bottle.
  - *Hemispherical*: Cut a Styrofoam ball in half. Sand down the base of the hemisphere until it is flat. Attach with strings or hinge made out of packing tape.

Figure 5. Construction of a paper nose cone. Left: rolling 8.5x11" cardstock into the shape of a cone and taping it on the edge to hold it together. Right: finished paper cone with the base trimmed to fit the top of the water bottle.

    - *Blunt*: You can skip building the cone and your rocket will still be flightworthy. It just won't fly as high as it will with a cone.
- (Optional) Parachute: If you have a "pointy" nose cone, you can construct a parachute for your rocket. One design inspiration is shown in Figure 6.
    - Cut one plastic bag into the shape of a square about 8-10 inches on a side.
    - Fold the bag along opposite corners to make a large triangle.
    - Fold again at the long corners to make a medium triangle.
    - Continue to fold until your triangle is in the shape of a wedge.
    - Trim the base of the folded bag so that the long edges of the triangle are equal length.
    - Cut about 1" off the top of the triangle. This will make a hole in the center of the parachute, which will make the parachute more stable during descent.
    - Unfurl the bag on the table. It should be roughly in the shape of a circle, with a small hole cut in the middle.
    - Cut eight equal lengths of thread, about 18 inches long.
    - Tie (best) or tape each string at the edge of the bag, in equal sections. See figure to get an idea of how that should look.
    - Gather the free ends of the eight strings together, and tie them into a bundled knot.
    - Attach the knot to the top of the bottle, centered, using packing tape or epoxy.
    - Roll up the parachute and strings carefully and set on top of the bottle.
    - Cover the parachute with the nose section, and secure the nose with two pieces of tape on one side (like a hinge).
- Fins: Choose a template from one of the fin options at the end of this packet, or come up with your own. Cut out the template and use it as a

Figure 6. One way to build an effective parachute is shown in this photograph. Be mindful of the hole in the center. It's there for good reason!

pattern. Using your fine-point marker, trace out three fins on the posterboard with your pattern. Sand down the rough edges of the fins with sandpaper. (Optional: if you researched homework question seven well, then you can use what you learned to shape your fin edges for high performance). Attach your fins as follows:

- Mark three vertical lines on the flat part of the bottle nearest the bottom. Make sure the three vertical lines are divided equally into thirds along the bottle circumference. See the instructor for ideas on how to do this.
- Align each fin against the vertical line, and with the help of your construction partner, secure the fin on both sides of the bottle with packing tape. Use enough tape so the fin holds securely, but not so much that the base gets weighed down.
- Repeat for each fin until complete.

Helpful hint: It is *much* easier to attach the fins to a pressurized bottle. An easy way to pressurize the bottle is to place it, cap removed, into a freezer for about ten minutes. Remove the bottle from the freezer and immediately cap the bottle. As the bottle cools, the air inside will expand and pressurize the bottle. Keep the cap on the bottle until the fins are finished.

Test your rocket for stability. Tie a string around the finished rocket at its center of gravity (that's the point where the rocket balances without tipping forward or backward). Place the rocket into the airflow of the high-speed fan, as shown in Figure 7. If the rocket is stable, the nose will point toward the fan without drifting outward. If the rocket is unstable, the nose will drift away. If unstable, stabilize your rocket using one of the techniques you learned in pre-lab Question 1. Re-test the rocket and repeat as needed until your rocket is stable.

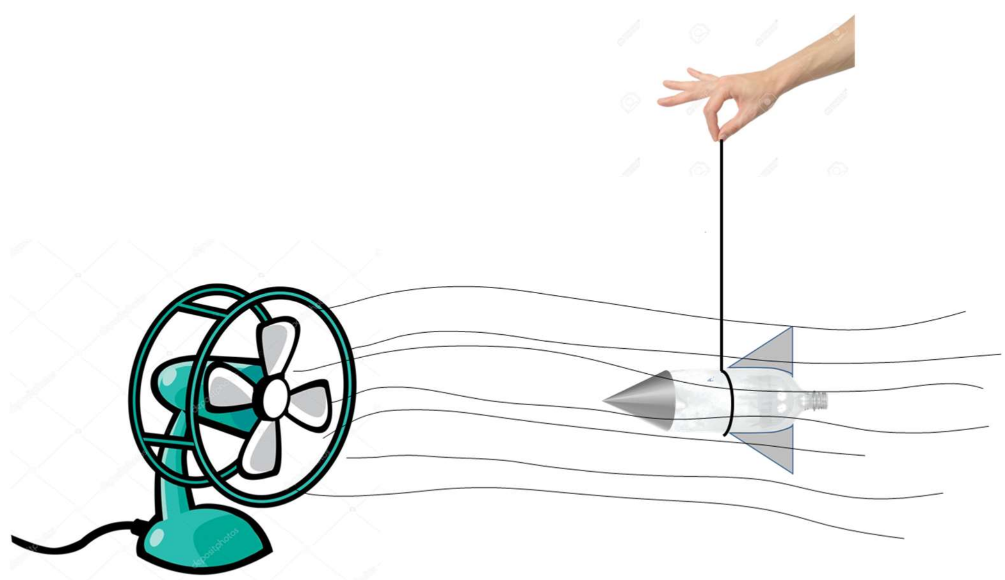
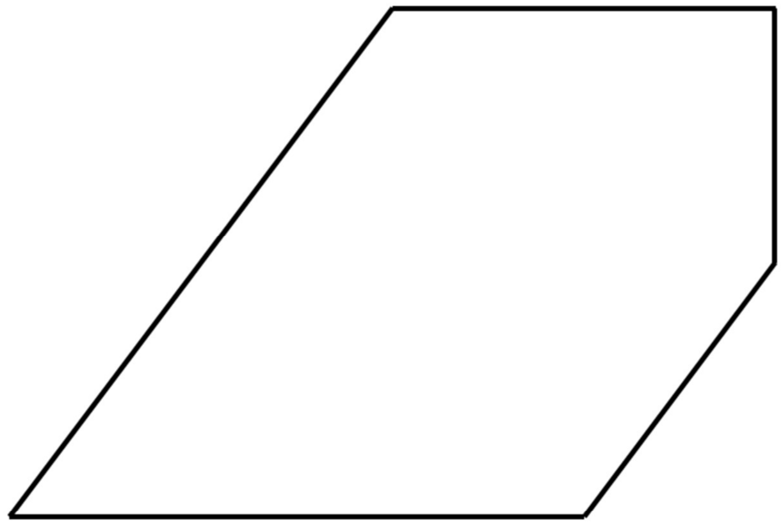
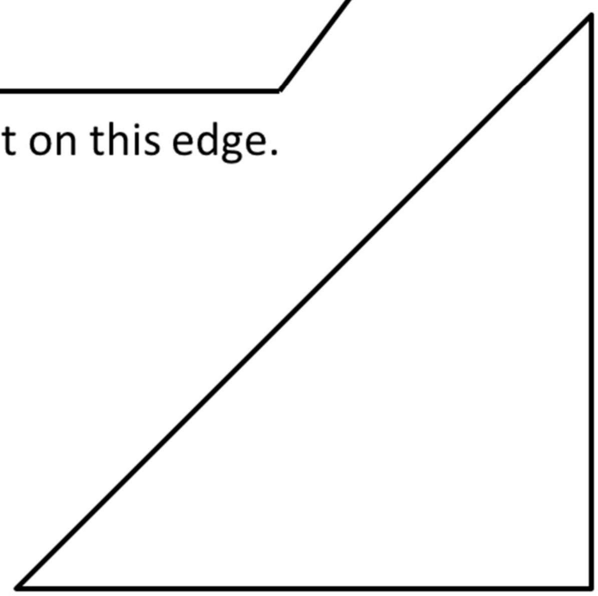


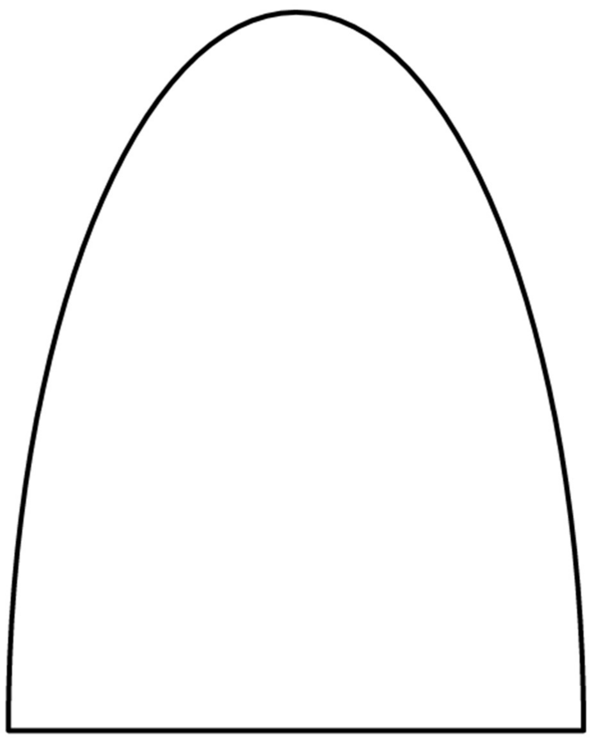
Figure 7. This is one way to test a rocket for stability. When stable, the nose of the rocket points directly into the airflow of a high-speed fan without the fins fishtailing outward.



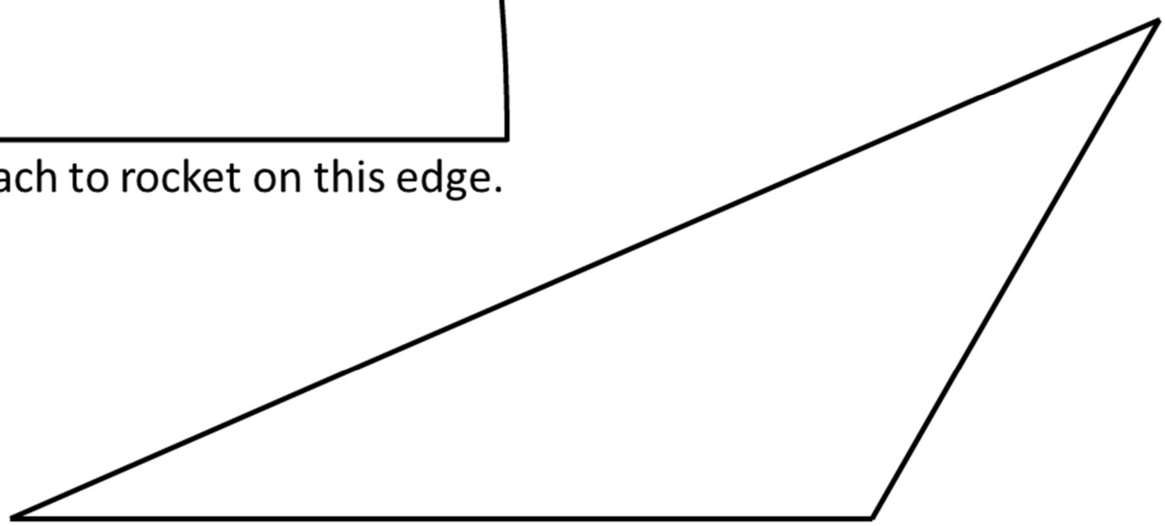
Attach to rocket on this edge.



Attach to rocket on this edge.



Attach to rocket on this edge.



Attach to rocket on this edge.